Met.O.893
METEOROLOGICAL OFFICE

the meteorological magazine

FEBRUARY 1976 No 1243 Vol 105
Her Majesty's Stationery Office

METEOROLOGICAL OFFICE Met.O.893

THE METEOROLOGICAL MAGAZINE

Vol. 105, No. 1243, February 1976

551.543.3:551.590.21

GLOBAL PRESSURE VARIATION AND THE 11-YEAR SOLAR CYCLE

By B. N. PARKER

SUMMARY

Global grid-point pressure data for January and July 1750–1958 were used to investigate possible variations during the 11-year solar cycle. At about latitude 65° in the winter hemisphere a tendency was found for anomaly centres to move eastwards from one annual stage to the next, completing a half-circuit of the globe during one solar cycle. In January the North Sea southerlies were above normal near solar maximum and below near minimum.

Charts of mean anomalies near solar maximum and minimum are presented and discussed, also charts of the difference in pressure between solar maximum and minimum. Significance of the variations is established by analysis of variance.

1. INTRODUCTION

Sunspots are relatively dark patches on the sun, emitting less visible light than surrounding areas, but still about 100 times more than the moon at full. They pass slowly across the face of the sun as it rotates and, if they last long enough, return to the same position in about 27 days (the synodic period), creating a transitory 27-day cycle in solar activity. Owing to causes which are still not fully understood the numbers of sunspots also vary very considerably over a period of about 11 years, the focus of much attention in previous work. Earlier in the century there was a spate of papers correlating sunspot numbers with purely local weather variations, but the tendency in recent years has been to investigate possible effects of the general circulation, and in pursuance of this trend this investigation deals with global-circulation anomalies.

2. THE SOLAR DATA

(a) *The basic data*

The index of solar activity used was the unsmoothed monthly mean sunspot number, R, available from 1749 onwards in publications of the Eidgenössische Sternwarte, Zurich (Parker, 1972). Many other indices exist either as refinements of the sunspot number or as measurements of other solar variables, but most of them have a reasonably high correlation with R, while none of them has so long a record and, since it was essential for the largest possible number of cycles to be included, it was felt that R was the only possible choice.

(b) *Classification into annual stages of the solar cycle*

Baur (1964) established new epochs of solar maximum and minimum from 1750 and his reasons for preferring them to epochs obtained by other methods were accepted.

It has been customary in the past to use the method of superimposed epochs in order to compare, or to mean, years in a similar position of different cycles, but if only one base is used for the superposition the variation of the phase lengths between cycles may lead to the comparison of unlike years. To overcome this problem to a certain extent two bases were used here—the month closest to the maximum and the month closest to the minimum, which were designated X and N respectively—and intervening Januarys and Julys were referred to these bases as successive 12-month intervals starting or ending at the time of the closest extremum under the classification $X-2$, $X-1$, X, $X+1$, $X+2$, $X+3$, $X+4$, $N-2$, $N-1$, N, $N+1$, $N+2$, $N+3$, where $X-2$ denotes a month which is between 30 months and 18 months before the next maximum and $N+3$ is 30 to 42 months after a minimum. Thirteen annual stages rather than 11 were used in order to incorporate into the list of classified months most of the years in long cycles which would otherwise have been neglected.

The classification system was to a certain extent subjective, owing to the variable length of the cycles, in that while most years could have been placed quite definitely in only one stage, there were occasions when in a short cycle a maximum occurred three years after a minimum; in such a case X was used rather than $N+3$. Similarly N rather than $X+4$ was allotted to a minimum falling four years after a maximum. Intervening months were entered under both headings where appropriate. In the longest cycles some months were of necessity omitted altogether. Table I shows which months were used in each annual stage and draws attention to the omission or duplication of dates when this system is used.

The only claim made on behalf of this classification is that it is probably better than one in which merely a single base is used. Other systems which were considered included classifications similarly based on solar maximum and minimum but using fifths of the Wolf number (R) interval between extrema, or otherwise specified absolute values of R as positional criteria. However, it was decided that these latter would not be usable in practice since they would involve forecasting the value of the sunspot maximum up to five years ahead instead of just forecasting its date about two years ahead.

3. The pressure data

These were extracted from the January and July mean pressure charts produced for 1750–1962 by Lamb and Johnson (1966). This source was chosen since it provided the longest available series of homogeneously analysed global charts. The authors' caution regarding the validity of single values was noted, but it was felt that a procedure involving the averaging of anomalies over several cycles would yield more acceptable results on the edges of the analysed areas than the individual years warranted.

The data were available in the magnetic tape data bank of the Synoptic Climatology Branch in the form of grid-point pressure values at intervals of 5° of latitude and 10° of longitude for each January and July from 1750 to 1962. They had undergone comprehensive quality control, but as an additional check

TABLE I—ANNUAL STAGES OF THE SOLAR CYCLE FOR JANUARY AND JULY, CLASSIFIED ON THE BASIS OF THE NUMBER OF YEARS BEFORE OR AFTER THE NEAREST BAUR EXTREMUM.

January

X—2	*X*—1	*X*	*X*+1	*X*+2	*X*+3	*X*+4	*N*—2	*N*—1	*N*	*N*+1	*N*+2	*N*+3
M	M	1750	1751	1752	*1753*	*1754*	*1753*	*1754*	1755	1756	1757	1758
1759	1760	1761	1762	1763	1764	*1765*	*1765*	1766	1767	*1768*	*1769*	M
1768	*1769*	1770	1771	1772	*1773*	*1774*	*1773*	*1774*	1775	*1776*	*1777*	M
1776	*1777*	1778	1779	1780	1781	*1782*	*1782*	1783	1784	1785	*1786*	*1787*
1786	*1787*	1788	1789	1790	1791	1792†	1796	1797	1798	1799	1800	1801†
1803	1804	1805	1806	1807	*1808*	*1809*	*1808*	*1809*	1810	1811	1812	1813
1814	1815	1816	1817	1818	1819	1820	1821	1822	1823	1824	1825	1826†
1828	1829	1830	1831	*1832*	*1833*	M	*1832*	*1833*	1834	*1835*	*1836*	M
1835	*1836*	1837	1838	1839	1840	1841	1842	1843	1844	1845	*1846*	*1847*
1846	*1847*	1848	1849	1850	1851	1852†	1854	1855	1856	1857	*1858*	*1859*
1858	*1859*	1860	1861	1862	1863	1864	1865	1866	1867	*1868*	*1869*	M
1868	*1869*	1870	1871	1872	1873	1874†	1877	1878	1879	1880	1881	*1882*
1882	1883	1884	1885	1886	1887	*1888*	*1888*	1889	1890	1891	*1892*	*1893*
1892	*1893*	1894	1895	1896	1897	1898†	1900	1901	1902	1903	*1904*	*1905*
1904	*1905*	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	*1916*
1916	1917	1918	1919	1920	*1921*	*1922*	*1921*	*1922*	1923	1924	1925	*1926*
1926	1927	1928	1929	1930	1931	*1932*	*1932*	1933	1934	*1935*	*1936*	M
1935	*1936*	1937	1938	1939	1940	1941	1942	1943	1944	*1945*	*1946*	M
1945	*1946*	1947	1948	1949	1950	1951	1952	1953	1954	1955	*1956*	*1957*
1956	*1957*	1958										

July

X—2	*X*—1	*X*	*X*+1	*X*+2	*X*+3	*X*+4	*N*—2	*N*—1	*N*	*N*+1	*N*+2	*N*+3
M	M	M	1750	1751	1752	*1753*	*1753*	1754	1755	1756	1757	1758
1759	1760	1761	1762	1763	*1764*	*1765*	*1764*	*1765*	1766	*1767*	*1768*	M
1767	*1768*	1769	1770	1771	1772	*1773*	*1773*	1774	1775	*1776*	*1777*	M
1776	*1777*	1778	1779	1780	1781	*1782*	*1782*	1783	1784	*1785*	*1786*	M
1785	*1786*	1787	1788	1789	1790	1791†	1796	1797	1798	1799	1800	1801
1802	1803	1804	1805	1806	1807	*1808*	*1808*	1809	1810	1811	1812	1813
1814	1815	1816	1817	1818	1819	1820	1821	1822	1823	1824	1825	1826
1827	1828	1829	1830	*1831*	*1832*	M	*1831*	*1832*	1833	1834	*1835*	*1836*
1835	*1836*	1837	1838	1839	1840	*1841*	*1841*	1842	1843	1844	*1845*	*1846*
1845	*1846*	1847	1848	1849	1850	1851†	1853	1854	1855	1856	1857	*1858*
1858	1859	1860	1861	1862	1863	1864	1865	1866	1867	*1868*	*1869*	M
1868	*1869*	1870	1871	1872	1873	1874†	1876	1877	1878	1879	1880	1881
1882	1883	1884	1885	1886	*1887*	*1888*	*1887*	*1888*	1889	1890	*1891*	*1892*
1891	*1892*	1893	1894	1895	1896	1897†	1899	1900	1901	1902	1903	*1904*
1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	*1915*	*1916*
1915	*1916*	1917	1918	1919	1920	*1921*	*1921*	1922	1923	1924	1925	*1926*
1926	1927	1928	1929	1930	*1931*	*1932*	*1931*	*1932*	1933	1934	*1935*	*1936*
1935	*1936*	1937	1938	1939	1940	1941	1942	1943	1944	*1945*	*1946*	M
1945	*1946*	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957

Italic figures denote a month which has been repeated in another stage; a dagger (†) shows that some months have been omitted in a long cycle. Where data are missing, or where a month would duplicate an extremum, M is entered.

the charts were printed out and drawn up, and a random selection was compared closely with the original charts. The fact that this process uncovered no significant differences between the two, while not necessarily giving support to an argument that such differences do not exist anywhere in the series, is taken as an indication of above-average reliability of the data, when added to the fact that no marked deviations from smooth isobars were found while the charts were being drawn. Programs were written in the METO language (Craddock, 1966) and run on the Meteorological Office KDF 9 and IBM 360/195 computers.

4. Treatment and results

(a) *Normal charts*

The first process was the computation of January and July normals for the period 1750–1958; these were means of 209 values in the area 25°–70°N, 80°W–30°E, at least 160 values in almost all the area 10°–75°N, 110°W–70°E and at least 114 values in almost all the area 45°S–80°N, 120°W–150°E.

(b) *The annual stages, $X-2$ to $N+3$*

(1) The next processes were the computation of mean charts for each stage and, from these and from the normal charts, the production of anomaly charts for each of the 13 annual stages. Within the area 20°–70°N, 90°W–40°E most of these were based on 18 to 20 cases, but the $N+3$ stage was based on 13 Januarys and 10 Julys (see Table I). Points outside the area stated were covered by fewer years than this.

It had originally been thought unlikely that individual stages would have much in common with adjacent stages, but an examination of the winter hemispheres brought to light a tendency for features in the higher latitudes centred around 65° latitude to move eastwards from one stage to the next. The Hovmöller diagram, at Figure 1 (a), of the change in longitude of January pressure anomalies at 65°N within the mean solar cycle, demonstrates a temporal coherence of spatially associated anomalies that is difficult to ignore; it shows a double-wave structure, each phase of which progresses around half the hemisphere during one solar cycle.

Further verification of the effect is provided by Figure 1(b) which shows that it is also apparent at the same latitude in the southern hemisphere. It should be noted that this diagram is based on many fewer data than is Figure 1(a) and must not be considered to provide more than confirmatory evidence, but it also has a double-wave structure, which tends to be out of phase with that in the northern hemisphere, i.e. at a given longitude and stage the sign of northern-hemisphere anomaly tends to be reversed in the southern hemisphere (287 cases of reversal and 191 of non-reversal). It is difficult to see how two such patterns could have arisen by chance and Figure 1(c) presents, for comparison, the same data as in Figure 1(a) rearranged into random order of annual stages by using a random-number generator on the numbers 1 to 13 to represent $X-2$ to $N+3$. It is fairly obvious that the redistribution has completely destroyed the pattern which was earlier apparent.

(2) Anomalies from the 1750–1958 normal for each annual stage were extracted for points at which the circulation indices are commonly measured. In January there were several details worthy of note and among the most interesting was the oscillation between solar maximum and minimum of the North Sea southerlies. In each of the three stages near maximum ($X-1$, X, $X+1$) the North Sea southerlies, measured as the pressure difference at 55°N between 10°E and 0°, were above normal, while near minimum ($N-1$, N, $N+1$) they were below normal.

(c) *Years grouped in phases*

The initial tendency in this investigation was to concentrate on groups of adjacent annual stages rather than to consider the stage-to-stage variations, since it was originally thought unlikely that the atmosphere actually reacted to

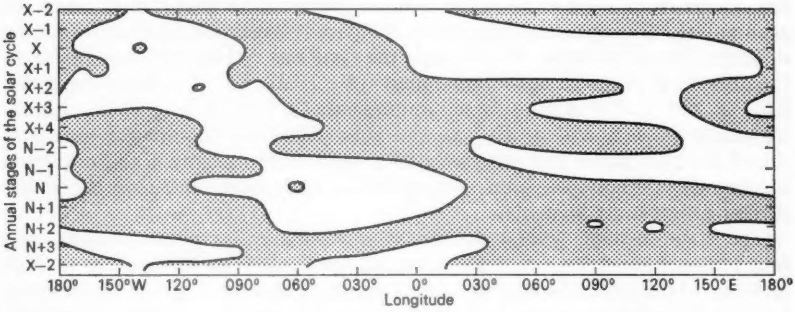


FIGURE 1(a)—CHANGE OF POSITION OF MEAN PRESSURE ANOMALIES FOR JANUARY AT 65°N THROUGH THE SOLAR CYCLE FOR THE PERIOD 1750–1958

Areas of negative anomaly are stippled.

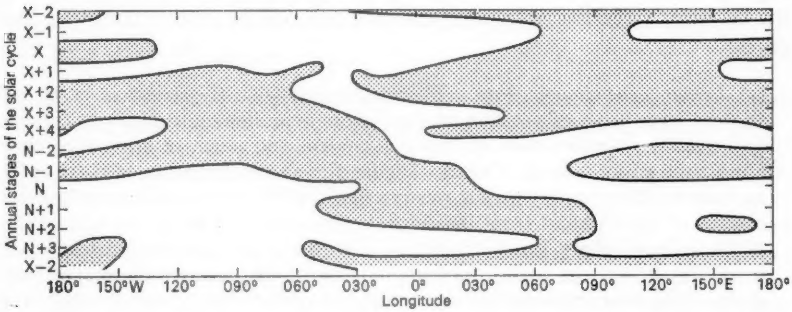


FIGURE 1(b)—CHANGE OF POSITION OF MEAN PRESSURE ANOMALIES FOR JULY AT 65°S THROUGH THE SOLAR CYCLE FOR THE PERIOD 1750–1958

Areas of negative anomaly are stippled.

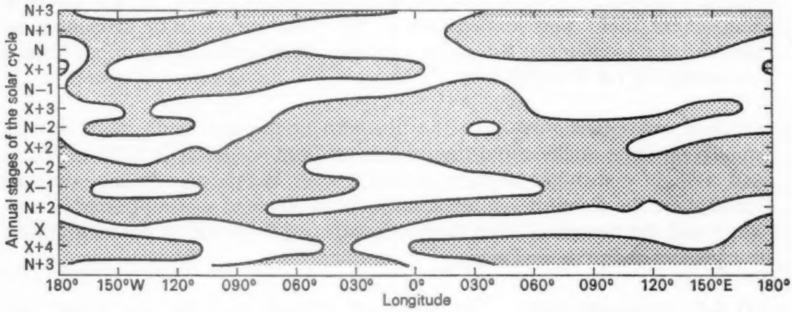


FIGURE 1(c)—CHANGE OF POSITION OF MEAN PRESSURE ANOMALIES FOR JANUARY AT 65°N WHEN THE ANNUAL STAGES OF THE SOLAR CYCLE ARE PUT IN RANDOM ORDER

Areas of negative anomaly are stippled.

the change from $X+2$ to $X+3$ for instance, but possible that it might show an accumulated difference between one set of adjacent stages and another in a totally different part of the cycle. Accordingly the cycle was divided into four phases in the following manner: maximum phase ($X-1$, X, $X+1$), descending phase ($X+2, X+3, X+4, N-2$), minimum phase ($N-1, N, N+1$) and ascending phase ($N+2$, $N+3$, $X-2$), and anomalies from the normal were produced for each phase and analysed and those for the maximum and minimum are shown in Figure 2. Lamb (1972) has already commented on these, but further points must be made.

The stage-to-stage spatial coherence of anomalies, as already stated, was much greater than was originally expected, particularly in the middle to high latitudes of the winter hemisphere, but it appeared that the stages of the descending and ascending phases in both January and July were less closely interrelated than those of the maximum and minimum phases, despite the duplication of some years in the ascending and descending phases and the lack of duplication at the extremes. A closer examination of the 'progression' of anomalies in Figures 1(a) and (b) makes this point quite well for 65°N and 65°S in that at the extremes smoother changes of position are evident that in the other two phases.

(1) *January, maximum phase.* The stages on which this chart is based all showed large areas of positive anomaly from Scandinavia to Novaya Zemlya and over the western part of North America, and negative anomalies over almost the entire Atlantic Ocean. Figure 2(a) shows the mean of these to be an accentuation, mainly on the western flank, of all the northern-hemispheric centres of action apart from the Azores anticyclone. This is not true of the southern hemisphere, however, and there seems to be a tendency towards the lows' filling and the highs' declining slightly, with negative anomalies predominating over the oceanic subtropical anticyclone belt, causing a decrease in zonal flow.

(2) *January, minimum phase.* The annual stages each showed zonality in the North Pacific and a slackening of the zonal gradient over the North Atlantic brought about by the filling of the Iceland low. In the southern hemisphere there were indications in all three stages of a deepening or northward movement of the eastern Atlantic lows and a filling or southward movement of the Weddell low.

(3) *July, maximum phase.* In the northern hemisphere each stage showed small positive anomalies along the arctic coast from Scandinavia to Novosibirsk and a slightly stronger negative anomaly over Labrador. In the southern hemisphere the mean of -3 mb south of New Zealand was supported in each stage and the westerlies were slackened between 60°S and Antarctica almost everywhere except in the Pacific.

(4) *July, minimum phase.* The stages all showed cyclonic anomalies over Europe, central Siberia and Alaska, in the Weddell Sea and south of South Africa. Anticyclonic anomalies occurred rather weakly in each stage from the Davis Strait to northern Norway and more strongly south-west of Cape Horn and south of Australia and New Zealand.

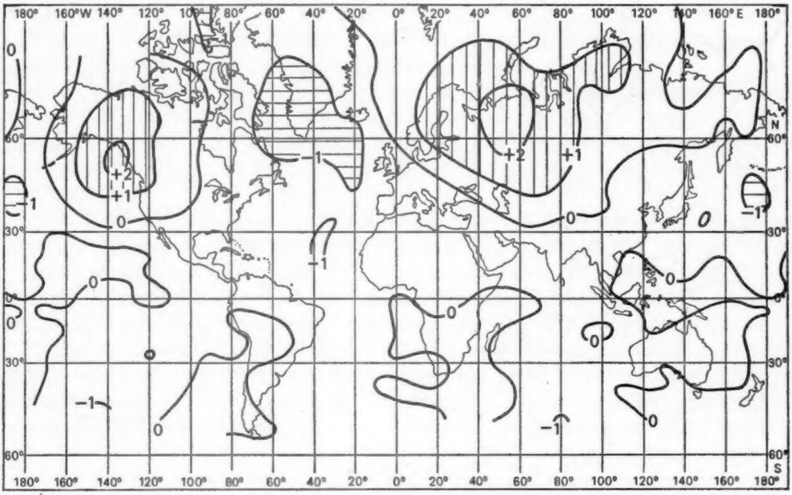


FIGURE 2(a)—PRESSURE ANOMALIES FOR JANUARY, MEANED FOR YEARS NEAR MAXIMA OF THE SOLAR CYCLE $X-1$, X, $X+1$, FOR THE PERIOD 1750–1958

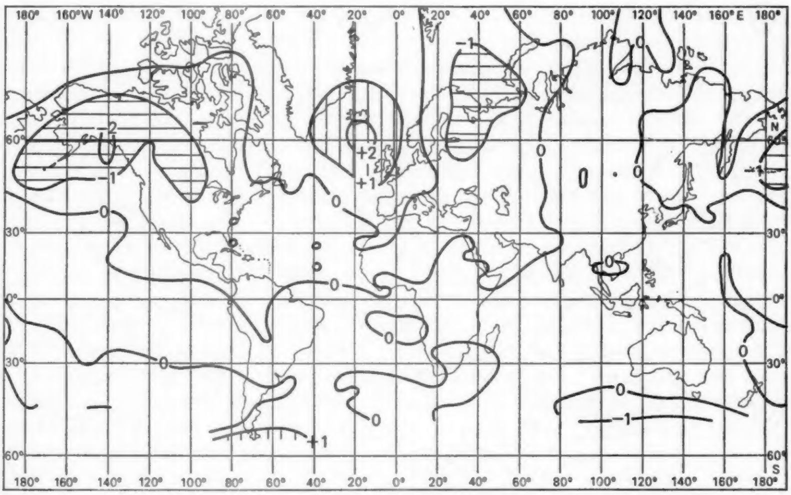


FIGURE 2(b)—PRESSURE ANOMALIES FOR JANUARY, MEANED FOR YEARS NEAR MINIMA OF THE SOLAR CYCLE $N-1$, N, $N+1$, FOR THE PERIOD 1750–1958

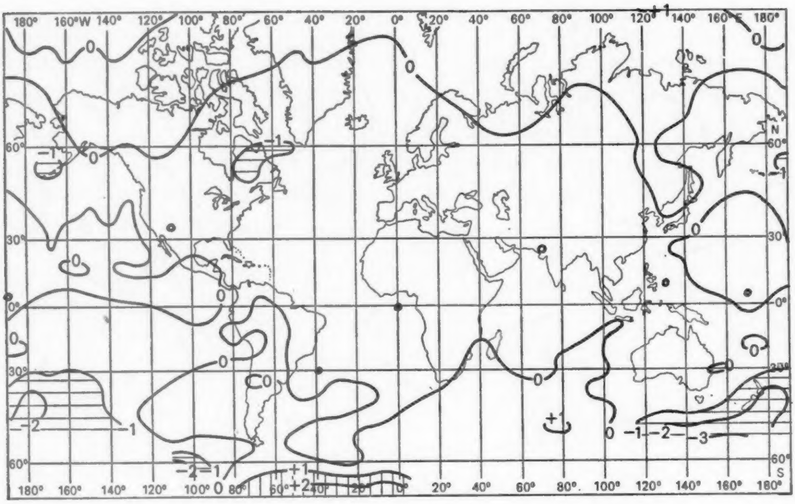


FIGURE 2(c)—PRESSURE ANOMALIES FOR JULY, MEANED FOR YEARS NEAR MAXIMA OF THE SOLAR CYCLE $X-1$, X, $X+1$, FOR THE PERIOD 1750–1958

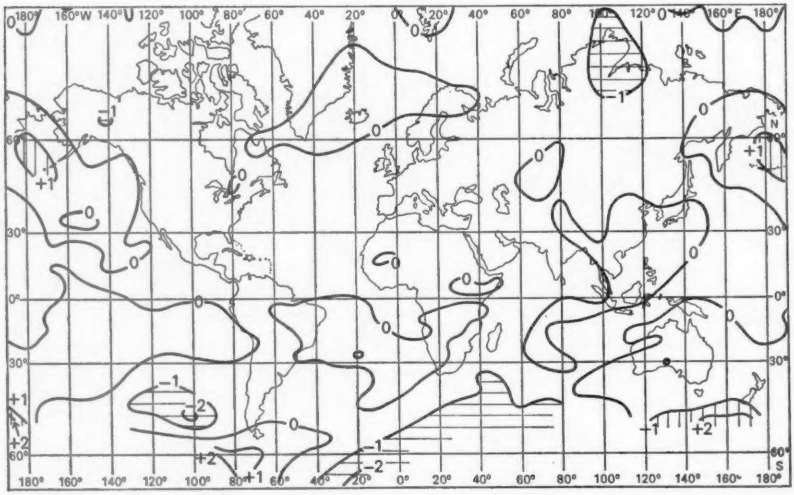


FIGURE 2(d)—PRESSURE ANOMALIES FOR JULY, MEANED FOR YEARS NEAR MINIMA OF THE SOLAR CYCLE $N-1$, N, $N+1$, FOR THE PERIOD 1750–1958

(d) *Differences between solar maximum and minimum*

Figure 1(a) also demonstrates a reversal of the sign of the anomaly at a given longitude from the maximum to the minimum phase.

The oscillation between solar maximum and minimum has been noted before by several authors (Pokrovskaya, 1969, discusses some of them) and as a comparison the anomalies meaned at each grid point for $N-1$, N, and $N+1$ were subtracted algebraically from those for $X-1$, X and $X+1$ using the data for 1750–1958.

The only really adequate tool for assessing the significance of these anomalies was an analysis of variance, which was used to compare the between-phase variance with the within-phase variance at each point. There were up to 113 degrees of freedom for the within-phase variance, depending on the position of the grid point, and one degree of freedom for the between-phase variance.

Figure 3 shows the difference between the mean pressure anomalies at solar maximum and minimum and areas significant at or beyond the 5 per cent, 1 per cent and 0·1 per cent levels. In January (Figure 3(a)) important differences are seen in the positive (1 per cent) which lessens the normal troughing into the Gulf of Alaska, the negative (5 per cent) which deepens the Iceland low and the positive (5 per cent) from the Gulf of Finland to the Barents Sea, which helps to cause the tendency over the North Sea towards southerliness near maximum and northerliness near minimum. There are also indications of a weakening of the Indian Ocean and Australian sectors of the subtropical anticyclone belt, but the largest significant area is the negative (1 per cent) centred over the eastern tip of Brazil, causing an eastward extension to the southern plunge of the Intertropical Convergence Zone (ITCZ) over South America in January.

Figure 3(b) shows the difference between the mean pressure anomalies for the solar maximum and minimum phases in July. The values are of course smaller in the northern hemisphere and larger in the southern hemisphere than those for January. The main features are a negative centre over the Aleutians (5 per cent) which strengthens the south-westerlies around the North Pacific anticyclone, positive over northern North America (5 per cent) increasing the north-easterlies over Hudson Bay, extending to an area of 0·1 per cent over Central America which slackens the easterlies over the Caribbean, negative anomalies again over the eastern tip of Brazil (1 per cent) suggesting a southern position of the ITCZ, positive again from east of South Africa to the Weddell Sea (1 per cent) and negative in a south-west to north-east direction across New Zealand (5 per cent).

Neither chart can be used effectively to prove or to disprove the so-called 'Law of accentuation' (Walker, 1915) which states that at solar maximum, pressure rises in areas of high pressure and falls in areas of low pressure, since the zero isopleth frequently runs through the centre of action, but it is perhaps more often true than not in January, particularly in the northern hemisphere.

There are many similarities between the January and July charts, and one's attention is drawn to the fact that the sign of the centres which are strongly marked in January is reversed in July only over New Zealand and south of Australia; all other centres retain the same sign.

Acknowledgement

The author is indebted to Mr P. Collison for carrying out the analyses of variance.

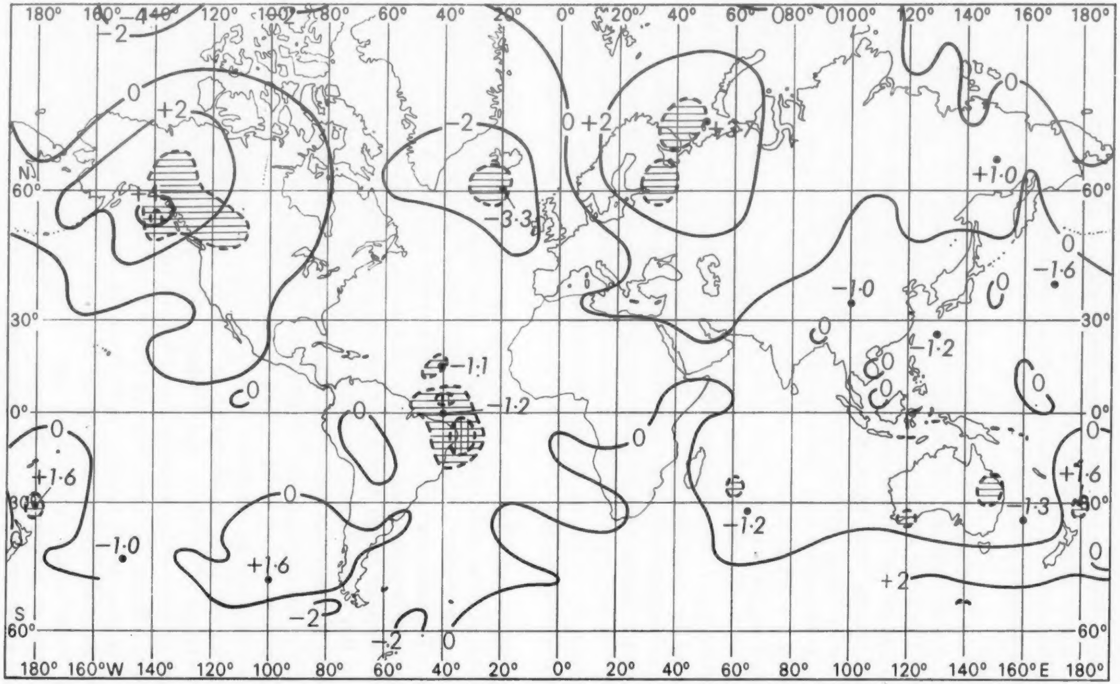


FIGURE 3(a)—DIFFERENCE BETWEEN PRESSURE AT MAXIMUM ($X-1$, X, $X+1$) AND MINIMUM ($N-1$, N, $N+1$) PHASES IN MILLIBARS, AND SIGNIFICANT AREAS BY ANALYSIS OF VARIANCE FOR JANUARYS, 1750–1958

Hatched area significant at 5 per cent or beyond, cross-hatched 1 per cent or beyond.

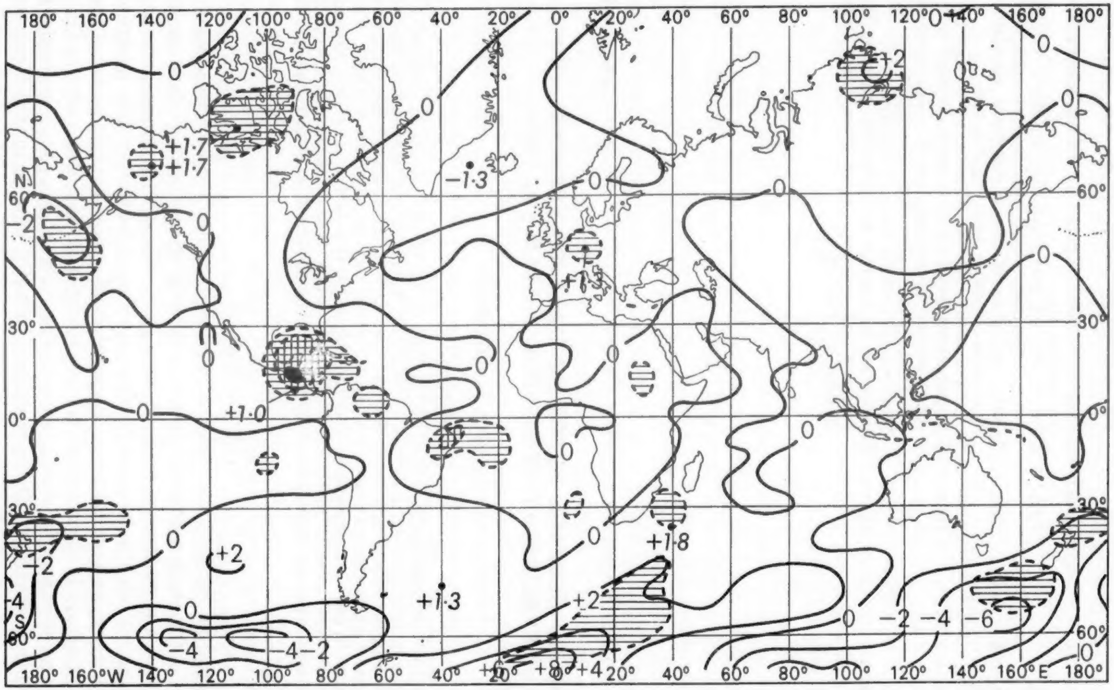


FIGURE 3(b)—DIFFERENCE BETWEEN PRESSURE AT MAXIMUM ($X-1$, X, $X+1$) AND MINIMUM ($N-1$, N, $N+1$) PHASES IN MILLIBARS, AND SIGNIFICANT AREAS BY ANALYSIS OF VARIANCE FOR JULYS, 1750–1958

Hatched area significant at 5 per cent or beyond, cross-hatched 1 per cent or beyond, and solid area 0·1 per cent.

REFERENCES

BAUR, F.	1964	Meteorologische Beziehungen zu solaren Vorgängen. I. Teil, Neufestsetzung der Epochen der Minima und Maxima der Sonnenflecken. *Met Abh, Berlin*, **50**, (3).
CRADDOCK, J. M.	1966	A simple computer language for the statistician. *The Statistician*, **16**.
LAMB, H. H.	1972	Climate: Present, past and future, Volume 1, Fundamentals and climate now. Methuen (London).
LAMB, H. H. and JOHNSON, A. I.	1965	Secular variations of the atmospheric circulation since 1750. *Geophys Mem*, **14**, No. 110.
PARKER, B. N.	1972	Keeping up with sunspots. *Weather*, **27**, pp. 247–251.
POKROVSKAYA, T. V.	1969	Synoptic-climatological and solar-geophysical long-range weather forecasting, Part II. Gidrometeoizdat (Leningrad). (Translation available in the Meteorological Office Library, Bracknell.)
WALKER, G. T.	1915	Correlation in seasonal variations of weather, VI, Sunspots and pressure. *Mem Indian Met Dept*, (Poona), **21**, Part 12.

551.501.771

THE USE OF SURFACE SYNOPTIC DATA TO ESTIMATE UPPER-LEVEL RELATIVE HUMIDITY OVER THE SEA

By P. R. JONAS

SUMMARY

Data from routine radiosonde ascents and surface observations have been analysed to determine the feasibility of using relative humidity estimates derived from surface reports in upper-air analyses where radiosonde data are scarce. It is demonstrated that the errors of the estimates are less than those of a 12-hour forecast used as a background field. The best parameter to use for estimating relative humidity at the standard levels of 850, 700 and 500 mb is the current weather but these estimates can be improved by using additional data such as the cloud type. An example of the effect of estimated data in an objective analysis is presented.

1. INTRODUCTION

The specification of the initial fields of relative humidity, or of water-vapour mixing ratio, for use in numerical models of the atmosphere used for short-range forecasting is a considerable problem in regions where radiosonde data are scarce. Whereas satellite data can provide estimates of the temperature structure in sparse-data regions over the sea, the problem of remote determination of the humidity structure is more complex. At present it is possible to obtain little more than an estimate of the total water content in a column of the atmosphere from satellite observations. In the absence of humidity data, as in the absence of temperature data, the models use a background or first-guess field which can be derived from climatology or from a previous run of the forecast model. However, because of the small-scale structure of humidity fields, the use of these fields can often result in considerable errors in the subsequent analysis.

This note describes a method by which estimates of the relative humidity at 850, 700 and 500 mb can be derived from synoptic surface reports of cloud and weather. The large number of surface reports received from merchant ships can then be used to estimate the upper-level humidity, these estimates being better than the use of a background field. These humidity estimates can be combined with humidity data into an objective analysis and in this note the effect of such data on an analysis is described.

Previous studies of the correlation of surface observations and upper-level humidity have been reported by Chisholm *et alii* (1968). They examined the statistics of dew-point depression using a decision-tree analysis for reliable estimators of upper-level humidity and for less significant cases they derived relations giving the probability of occurrence of various categories of dew-point depression. Since many numerical models use relative humidity as an analysed variable and since this is more readily interpreted in terms of physical processes it was decided to undertake a similar analysis of relative humidity instead of dew-point depression. The significance of an estimate of dew-point depression used by Chisholm *et alii* (1968) was determined by the condition that, at 850 mb, 45 per cent of the cases had dew-point depressions within a 3-deg spread and 60 per cent of cases were within 5 deg. This implies that the results were judged significant if the estimated dew-point was within 2·5 deg of the actual dew-point on 60 per cent of occasions or in terms of relative humidity, that the estimated relative humidity was within about 20 per cent of the actual relative humidity on these occasions. It was hoped that an analysis in terms of relative humidity would improve the accuracy of the estimates. The present analysis was carried out using standard-level humidity data obtained not only from standard-level observations but also from observations which incorporated special points within 50 mb of the standard level. In this way it was hoped that the estimated relative humidities would be more representative of a layer comparable in thickness to those used in many numerical models than those obtained using only standard-level observations. Such a vertical integration should also improve the correlation of the humidity and surface-weather observations.

2. The estimation of humidity

Data have been extracted from the surface and upper-air reports from 7 Atlantic weather stations and 4 island stations shown in Figure 1. The data were extracted over the period 14 August 1973–17 February 1975 and although some of the weather ships were withdrawn during this period all the available reports were included in the analysis since no detectable seasonal variation in humidity estimates was found. The extracted data consisted of the surface report and the mean relative humidity in successive 50-mb layers from 950 mb upwards, obtained using a trapezoidal integration of the standard and special-point temperature and dew-point data. The standard-level humidity data at 850, 700 and 500 mb were then obtained by linear interpolation between adjacent 50-mb layers. Histograms showing the distribution of the relative humidities at the three levels and the number of data analysed are shown in Figure 2.

The aim of this work was to provide estimates of relative humidity which could be derived from merchant-ship reports. These reports seldom contain detailed cloud observations ('8-groups'); because of this and the fact that 00 and 12 GMT observations from moving ships were to be used the estimates of relative

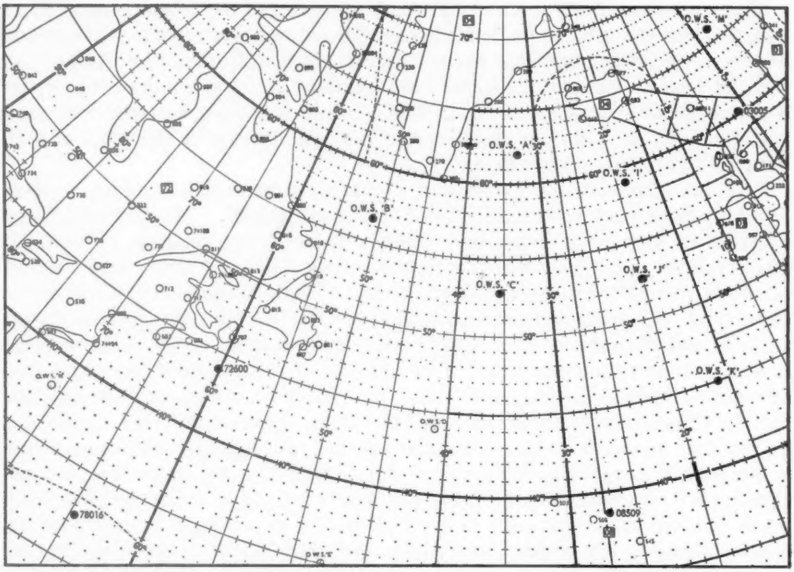


FIGURE 1—LOCATION OF RADIOSONDE STATIONS PROVIDING DATA USED IN THE ANALYSIS OF UPPER-LEVEL RELATIVE HUMIDITY

humidity were based on the reports of current weather (ww) and the standard cloud report ($N_HC_LhC_MC_H$); such estimators as pressure-tendency and past weather were not considered. This restricted analysis has other advantages since it may be possible to obtain estimates of these parameters by interpretation of satellite cloud photographs (Booth, 1973) or of satellite radiance data (Cooley *et alii*, 1970). If this becomes a reliable real-time possibility then the scope of the estimation of humidity could be extended.

There remains the problem of defining a 'reliable estimate of relative humidity'. It is clear that a mean relative humidity could be used but this would be in error on many occasions. Experiments using the Meteorological Office 10-level model (Benwell *et alii*, 1971) suggested that changes in the relative-humidity analysis over a 1000-km square by 10–20 per cent could give rise to significant changes both in 24-hour rainfall forecasts and in pressure forecasts amounting to 8 mb in 24 hours in regions of rapid development. It was hoped therefore that, particularly at the most significant 850-mb level, the estimates of relative humidity would be within about 15 per cent of the observations on the majority of occasions. The estimate of relative humidity derived from a sample of the observations was chosen to be the mid point of the narrowest humidity range containing 70 per cent of the observations. The use of such a median rather than a mean humidity for the estimate reduced the number of occasions when the estimate was in error by more than 15 per cent. Since the use of the estimated data is to reduce the errors in humidity analyses below the level found using the background field it would be desirable to obtain statistics of the differences between humidity background fields and analyses in regions where data exist. Unfortunately such

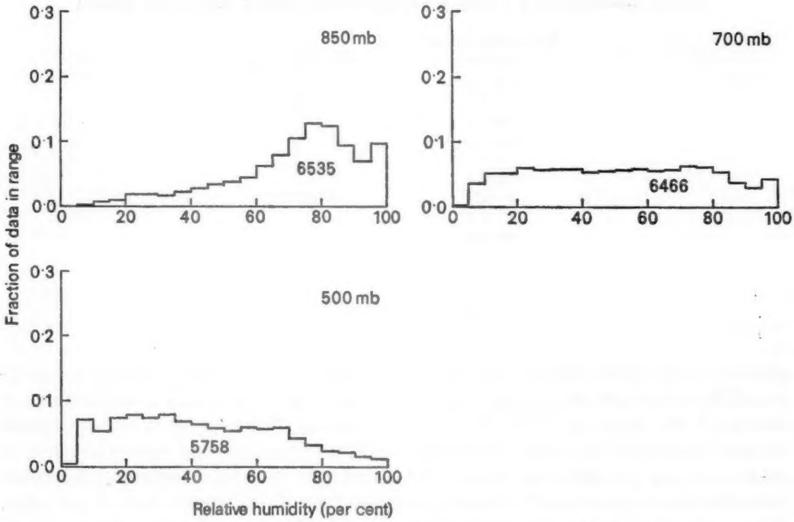


FIGURE 2—HISTOGRAMS SHOWING DISTRIBUTION OF HUMIDITY OBSERVATIONS AT THREE STANDARD LEVELS

data are not available but analysis of the Meteorological Office 12-hour forecasts (an updated 12-hour forecast is used as a background field for this model) suggests that monthly mean humidity errors in the vicinity of the weather ships are about 10 per cent in summer and 15–20 per cent in winter but no figures are available for the root-mean-square errors.

The observations were processed by splitting the sample of data into various categories of present weather and cloud type such that at least 5 per cent fell into each category. A best estimate of the humidity at the standard levels for each category was then obtained. Adjustments were then made to the types included in each category in an attempt to minimize the number of observations of humidity differing from the appropriate estimate by more than 15 per cent.

In the analysis the present weather was split into three categories, dry, showery or wet, the present-weather codes which were assigned to each category being shown in Table I. It was found that at no level was anything to be gained by further subdivision into separate cases of mist or fog (which were included as dry) or of snow or snow showers (included as wet or showery respectively).

At 850 mb it was found that in addition to the present weather the type of low cloud (C_L) was useful. It was found that cases with $C_L = 7$ (indicating bad weather) were best included with the wet cases and cases with $C_L = 3$ or 9 (cumulonimbus) were best included with cases where showers were indicated by the present-weather code. Somewhat surprisingly it was found that the total amount of cloud in the lowest group observed (N_H) was not a useful predictor even if the analysis was restricted to cases where low cloud was present but that the separate classification of very dry cases ($C_L = 0$, no low cloud) did improve the results to a small extent. The best estimates of the 850-mb relative humidities

TABLE I—WEATHER TYPES ASSIGNED TO PRESENT WEATHER CODES

Present-weather code	Weather type
0–12 28 30–37 40–49	Dry
13–19 25–27 29 80–99	Showery
20–24 38–39 50–79	Wet

derived from these classes are shown in Table II, histograms of the relative-humidity observations being shown in Figure 3. Using this combination of estimates the fraction of humidity observations differing from the estimated relative humidities by more than 15 per cent was 0·39 and the fraction in error by more than 20 per cent was 0·25. The mean and root-mean-square differences between the estimated and observed relative humidities were 2 and 18 per cent. If an estimate based on the entire data sample had been used only, 56 per cent of the data would have been within 15 per cent of the estimated relative humidity and the mean and root-mean-square differences would have been 11 and 23 per cent.

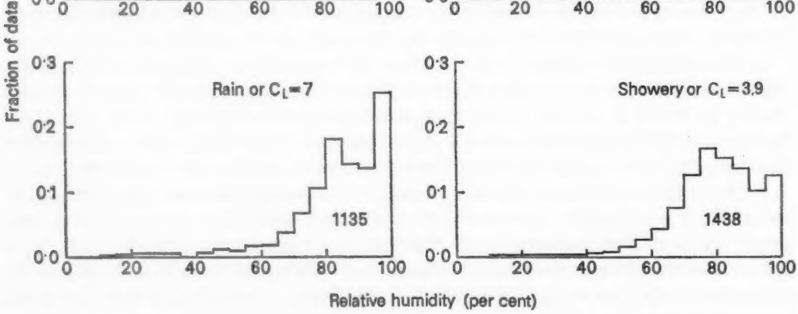


FIGURE 3—HISTOGRAMS SHOWING DISTRIBUTION OF RELATIVE HUMIDITY AT 850 MILLIBARS FOR THE VARIOUS WEATHER TYPES SELECTED TO PROVIDE THE BEST ESTIMATES OF HUMIDITY

TABLE II—ESTIMATES OF RELATIVE HUMIDITY AT 850 MILLIBARS

Weather type and C_L	Number of data	Estimated relative humidity *per cent*	Fraction of data within 15 per cent of estimate
Dry and $C_L = 0$	366	42	0·46
Dry and $C_L = 1,2,4,5,6,8$	3596	66	0·54
Showery or $C_L = 3,9$	1438	79	0·75
Wet or $C_L = 7$	1135	90	0·82

At 700 mb it was also found that the present weather was the main variable to be used in the analysis together with the low and medium cloud types. Reports with $C_L = 7$ or $C_M = 2$ (dense altostratus or nimbostratus) were included with the wet types and again $C_L = 3$ or 9 was taken to imply a showery type. The remaining 'dry' cases were split into three groups: the very dry at middle levels, with a report of no medium-level cloud ($C_M = 0$); the moist, with thicker medium-level cloud ($C_M = 6$, 7, 8 or 9); and the remainder which were included in a separate class. Table III shows the estimates of humidity at 700 mb based on this classification. The mean difference between the estimated and observed relative humidity is 2 per cent, 0·50 of the data are within 15 per cent of the estimate and 0·63 are within 20 per cent.

TABLE III—ESTIMATES OF RELATIVE HUMIDITY AT 700 MILLIBARS

Weather type, C_L and C_M	Number of data	Estimated relative humidity *per cent*	Fraction of data within 15 per cent of estimate
Dry and $C_M = 0$	1772	28	0·51
Dry and $C_M \neq 0,2,6,7,8,9$	594	36	0·36
Dry and $C_M = 6,7,8,9$	355	53	0·29
Showery or $C_L = 3,9$	1197	59	0·45
Wet or $C_L = 7$ or $C_M = 2$	1211	83	0·59

Inspection of Figure 2 shows that the distribution of relative humidity at 500 mb is much more uniform than at lower levels so that the estimated humidities will be less accurate. However, since the mixing ratio is lower at this level than at the other levels, forecasts are less sensitive to errors in the humidity analysis. To obtain a slight improvement in the estimate over a simple mean value, four categories were used. As at the lower levels the classification mainly used the three weather types, observations of $C_M = 2$ being included with the wet cases and $C_L = 3$ or 9 with the showery cases. The dry cases were again split into three groups: very dry, with C_M and $C_H = 0$; moist, with $C_M = 6$, 7, 8 or 9 and $C_H = 2$, 3, 7 or 9; and the remainder. The dry cases with cloud indicating moist conditions at 500 mb were included with the wet cases. The resulting

humidity estimates are shown in Table IV. The mean difference between the estimates and the observed humidities was 4 per cent with 0·52 of the data within 15 per cent of the estimate and 0·65 within 20 per cent.

TABLE IV—ESTIMATES OF RELATIVE HUMIDITY AT 500 MILLIBARS

Weather type, C_L, C_M, C_H	Number of data	Estimated relative humidity *per cent*	Fraction of data within 15 per cent of estimate
Dry and $C_M = 0$ and $C_H = 0$	1157	21	0·63
Dry and $C_M \neq 0,2,6,7,8,9$ or $C_H \neq 2,3,7,9$	2251	28	0·51
Showers and $C_L = 3,9$	1033	39	0·47
Wet and $C_M = 2$ and dry with $C_M = 6,7,8,9$ and $C_H = 2,3,7,9$	1317	60	0·47

These estimates of relative humidity can be incorporated with real data into an analysis scheme and could result in an improvement in the resulting humidity analysis. The next section shows an example in which estimated data have been used to improve a humidity analysis. The method of estimation provides a humidity estimate at 850, 700 and 500 mb from any ship report for which a valid present-weather code is reported. This can sometimes be improved if cloud reports are also obtained.

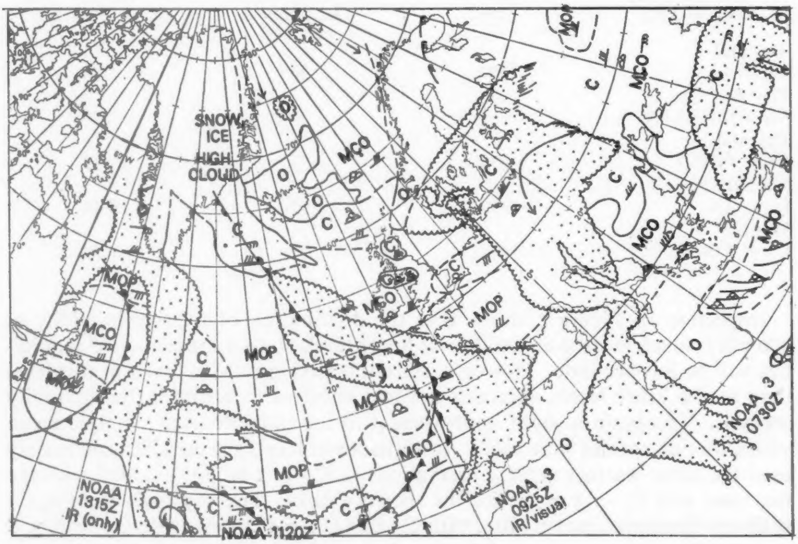


FIGURE 4—NEPHANALYSIS FOR 12 GMT ON 19 NOVEMBER 1974

3. A HUMIDITY ANALYSIS INCLUDING ESTIMATED DATA

The situation chosen for analysis was the chart for 12 GMT on 19 November 1974. The upper-level humidity structure is revealed in the nephanalysis (Figure 4) upon which have been superimposed the surface frontal positions extracted from the *Daily Weather Report* of the Meteorological Office. The main features over the Atlantic are the two bands of cloud associated with the surface fronts between which is an area of broken cloud with extensive convective activity.

The objective humidity-analysis system used for the fine-mesh, limited-area version of the Meteorological Office 10-level model has been described by Atkins (1974). The standard-level humidity observations are interpolated on to surfaces at 100-mb intervals from 350 to 950 mb and the analysis is carried out on these surfaces using a previous forecast field as a background analysis. Asymmetric weighting fields are given to the data to provide, in sparse-data areas, some retention of the shape of features on the background analysis.

The background analyses at 850 mb and 650 mb are shown in Figure 5. Inspection shows that the main frontal system in the eastern Atlantic is present but that behind the front an area of very dry air is apparent. This dry air extends to the southern boundary of the chart, breaking the moist area associated on the nephanalysis with the front in this area. The area of moist air to the east of Newfoundland is shown farther to the west than is indicated by the nephanalysis, resulting in a break in the moist area on the background analysis at about 45°N 47°W which is not obvious from the satellite observations. Therefore although the background analysis contains the general features of the humidity structure there are errors of positioning and intensity of some of the features. The background analyses are probably rather better than average owing to the large amount of subjective intervention which was being included at this date.

The effects of incorporating the radiosonde observations from Atlantic weather ships and land-based stations can be seen in the analyses presented in Figure 6. The main effect on the Atlantic analysis was due to the observations from Ocean Weather Station 'K'. This observation has demonstrated the background analysis error in this area and has raised the humidity at 850 mb from about 20 to 80 per cent which might be expected in a region of convective cloud. The observations from Stations 'I' and 'J' fit in quite well with the background analysis and only minor changes are produced. There are no other changes in the analysis over the North Atlantic because of the absence of data from these regions.

A large number of surface ship observations were obtained on this occasion, most of which, since they contained a valid present-weather code, were capable of yielding upper-level humidity estimates. In order to provide a reasonably uniform coverage of estimated data the area shown in Figure 7 was partitioned into areas of 7·5° of latitude by 7·5° of longitude and a maximum of one estimated observation was obtained for each area. Within the area shown this provides for a maximum of 39 observations which consisted of the first observation retrieved from the data bank for each area. In this case a total of 27 observations were extracted and these are plotted on Figure 7. Conventional notation is used for the plots of ww, C_L, C_M and C_H except that an O is plotted as a cloud symbol if a report of no cloud was obtained to distinguish this from cases of no observation of cloud. These data were used to provide estimates of relative humidity which were included in the analyses shown in Figure 8.

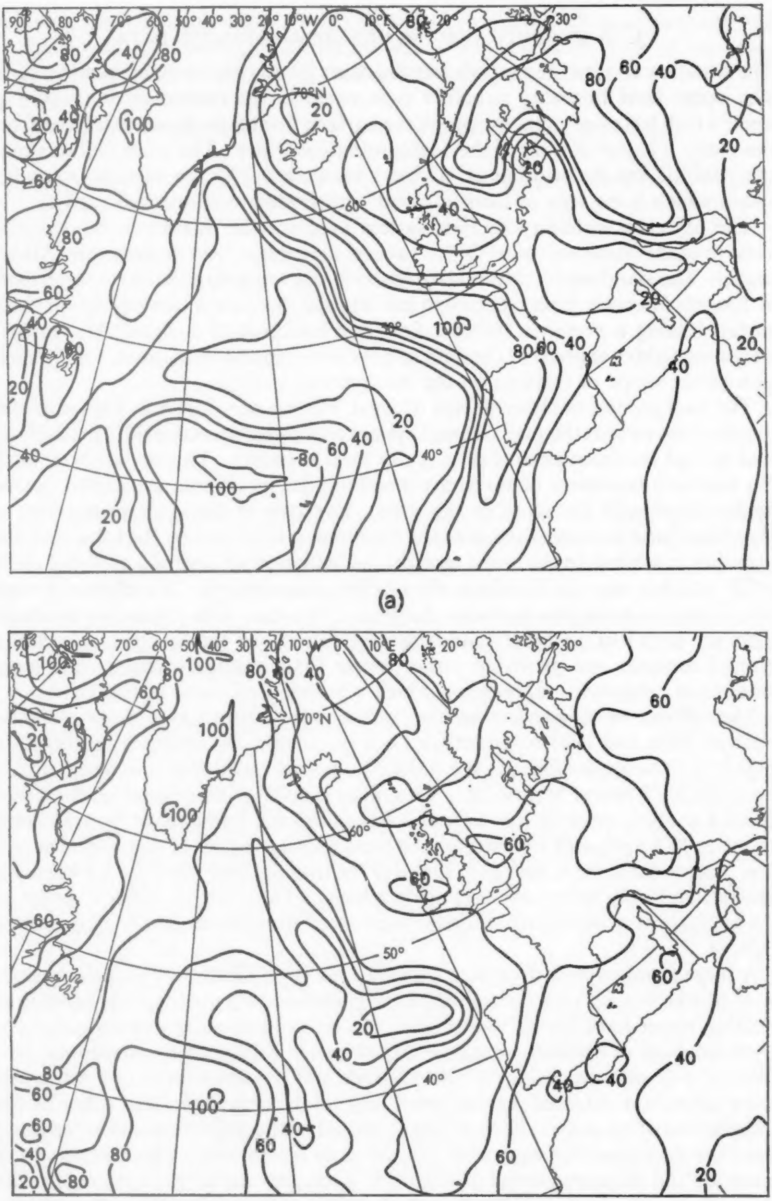
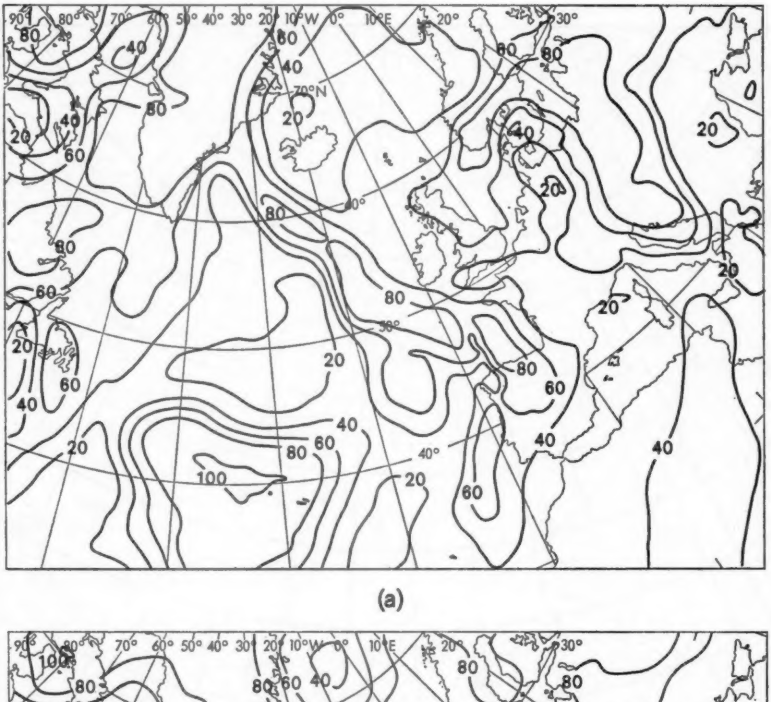


FIGURE 5—BACKGROUND RELATIVE-HUMIDITY ANALYSIS AT (a) 650 AND (b) 850 MILLIBARS FOR 12 GMT ON 19 NOVEMBER 1974



(a)

(b)

FIGURE 6—HUMIDITY ANALYSIS AT (a) 650 AND (b) 850 MILLIBARS FOR 12 GMT ON 19 NOVEMBER 1974 USING CONVENTIONAL RADIOSONDE DATA ONLY

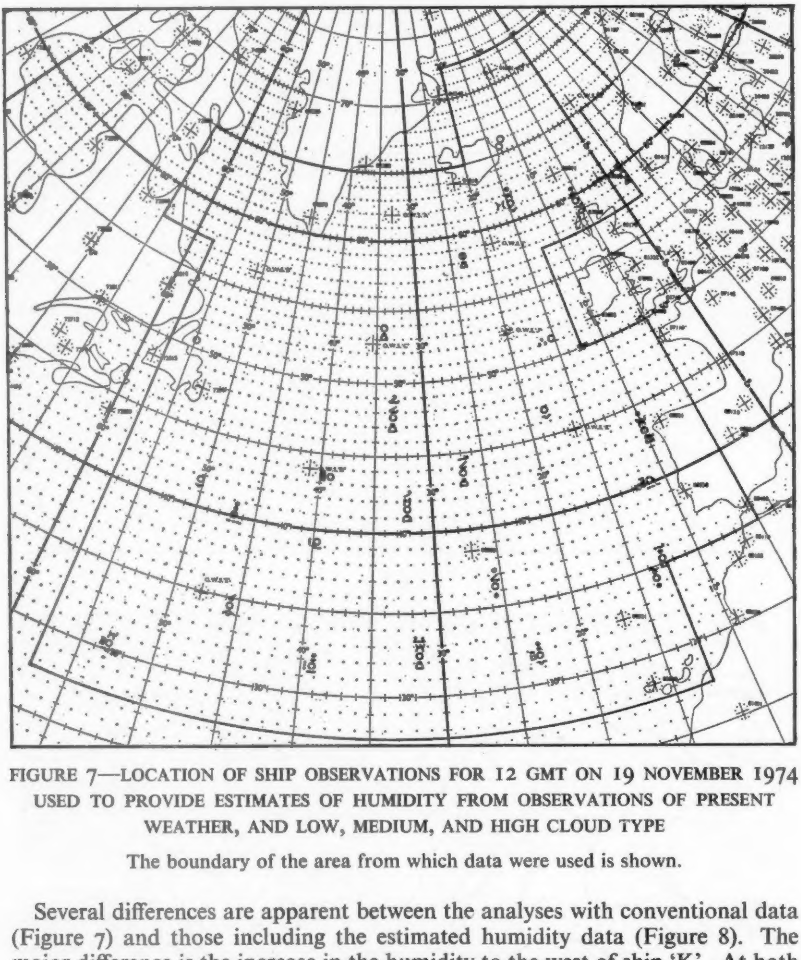
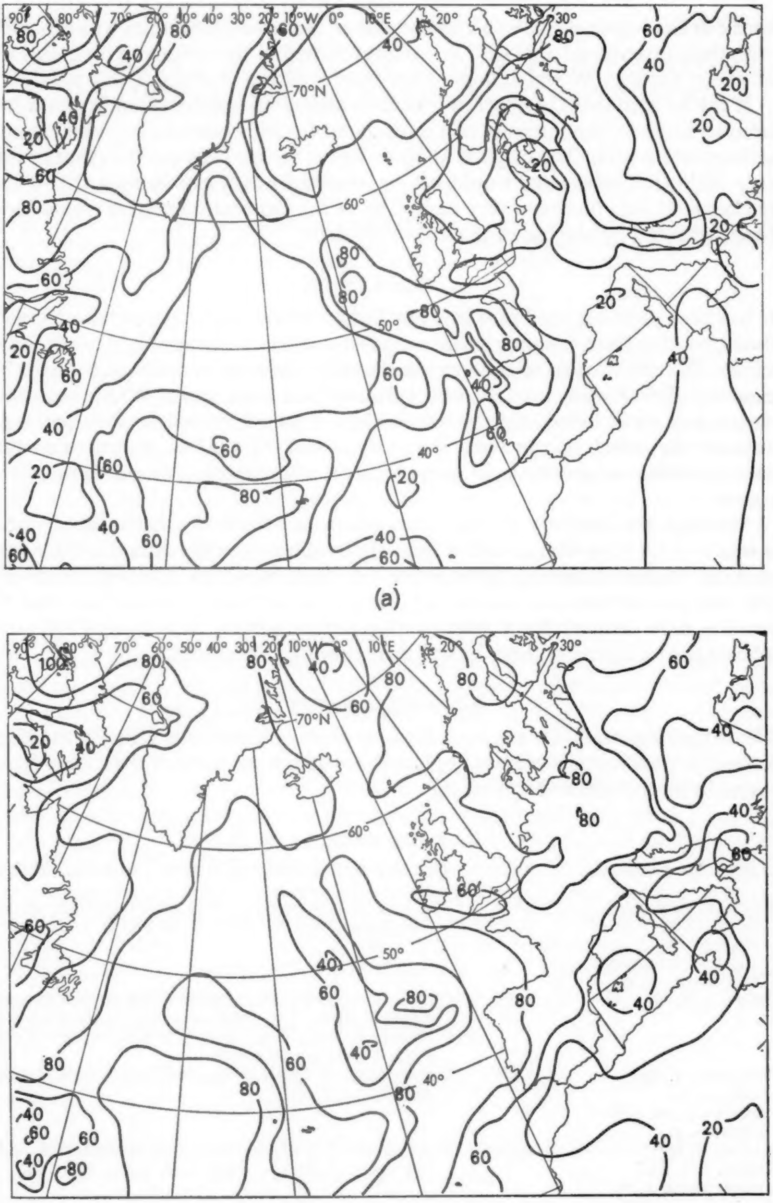


FIGURE 7—LOCATION OF SHIP OBSERVATIONS FOR 12 GMT ON 19 NOVEMBER 1974 USED TO PROVIDE ESTIMATES OF HUMIDITY FROM OBSERVATIONS OF PRESENT WEATHER, AND LOW, MEDIUM, AND HIGH CLOUD TYPE

The boundary of the area from which data were used is shown.

Several differences are apparent between the analyses with conventional data (Figure 7) and those including the estimated humidity data (Figure 8). The major difference is the increase in the humidity to the west of ship 'K'. At both of the levels presented the analysis is closer to that which could be inferred from the nephanalysis which showed convective cloud in this area. The analysis that includes estimated relative humidities has increased the extent of the moist zone near the southern boundary, again consistent with the nephanalysis indication of a belt of cloud linking the main frontal regions. The revised analyses to the south of Iceland are drier than the original analysis would indicate, this also being suggested by the nephanalysis which shows rather less cloud in this area than in the main region of frontal activity farther south. Other minor differences between the analyses include changes at about 40°N 35°W where the effect of the estimated data is to reduce the relative humidities. Although the position of this feature is not changed by the inclusion of estimated data the dry air behind it has been moistened in the revised analysis so that there is slightly less indication of a



(a)

(b)

FIGURE 8—HUMIDITY ANALYSIS AT (a) 650 AND (b) 850 MILLIBARS FOR 12 GMT ON 19 NOVEMBER 1974 INCLUDING ESTIMATED HUMIDITY DATA AT STANDARD LEVELS

break in the region of moist air to the east of Newfoundland than was observed with the conventional analysis. It is unfortunate that there were no observations at about 50°N 45°W which might have improved the analysis at this point.

It can be seen that the effect of including estimated relative humidity data has been to improve the intensity of the analysed features without introducing any serious new errors. The original analysis was comparatively good so that in this case major improvements would not be expected but it can be seen that if the background field had been very bad many of the important features would have been indicated by the use of the estimated data.

4. Conclusions

It has been demonstrated that it is possible to derive useful estimates of upper-level humidity from synoptic surface reports such as those reported by merchant ships. The errors in these estimates are smaller than the errors which might be expected if estimates based on a background field were used. When these estimated data are included in a scheme of objective humidity analysis the effect is to improve the correlation between the analysis and the analysis suggested by the corresponding nephanalysis in areas where conventional radiosonde data are scarce.

Although the coverage of data estimated from merchant-ship surface reports is much better than that of radiosonde observations over the Atlantic there are, as in the example discussed, appreciable areas from which no data can be derived. The analysis carried out in terms of cloud type and weather could be used to provide data derived from satellite cloud photographs if a computer-based scheme for interpreting these in real time could be developed.

Acknowledgement

The author is grateful for the contributions of those members of the Forecasting Research Branch of the Meteorological Office who have been involved at various stages in the progress of this work.

References

ATKINS, MARGARET J. 1974 The objective analysis of relative humidity. *Tellus*, **26**, pp. 663–671.

BENWELL, G. R. R., GADD, A. J., KEERS, J. F., TIMPSON, MARGARET S. and WHITE, P. W. 1971 The Bushby–Timpson 10-level model on a fine mesh. *Scient Pap, Met Off*, No. 32, HMSO.

BOOTH, A. L. 1973 Cloud type pattern recognition using environmental satellite data. 1st International Conference on Pattern Recognition, 30 Oct.–1 Nov. 1973. IEEE (New York), pp. 526–533.

CHISHOLM, D. A., BALL, J. T., VEIGAS, K. W. and LUTY, P. V. 1968 The diagnosis of upper-level humidity. *J Appl Met*, **7**, pp. 613–619.

COOLEY, D. S., BALL, J. T. and PAVLOWITZ, A. M. 1970 Layered cloud analyses derived from satellite and conventional data, *J Appl Met*, **9**, pp. 158–169.

551.525.2:625.7

A NOTE ON THE READINGS OF TWO DIFFERENTLY EXPOSED THERMOMETERS WHEN WATER FREEZES ON CONCRETE

By W. G. RITCHIE

Summary

When free water freezes on concrete, the temperature recorded by a thermometer with its bulb resting on the concrete is about —0·7°C and that recorded by a thermometer embedded so that the bulb is 1·25 cm below the concrete surface is about + 0·4°C.

Purpose of the experiment

It is standard practice in the Meteorological Office to expose at night on a slab of concrete an alcohol-in-glass minimum thermometer, slightly tilted from the horizontal so that the bulb rests on the concrete, and to call the minimum temperature recorded by this thermometer the 'concrete minimum temperature'. This temperature will, however, be affected by the air surrounding the bulb as well as by the concrete surface. It was thought that a thermometer with the bulb embedded just below the concrete surface would also record a temperature near to the concrete surface temperature. This experiment was devised to determine how nearly the temperature of the concrete surface is represented near freezing point by the readings of thermometers exposed in these two ways.

Experimental arrangements

The site of the experiment was the circle of mature concrete 23 m in diameter and from 20 to 30 cm thick in an open site on Wyton airfield which had been used in previous experiments (Ritchie and Virgo, 1973). For another experiment a mercury-in-glass thermometer had been partially embedded in the concrete so that the middle of the bulb was 1·25 cm below the surface (see Figure 1) and the embedding mortar had been coated with a thin layer of waterproof material. An alcohol-in-glass minimum thermometer slightly tilted from the horizontal so that the bulb rested on the surface was exposed near the embedded thermometer. To prevent accidental damage to the thermometers by hares, without materially affecting the exposure of the thermometers to the night sky, a light frame was placed over them. The frame was of angle-strip aluminium, 0·25 cm thick and 1·25 cm wide, in the form of an open 60-cm square with a 30-cm leg at each corner. The base of each leg was inserted into a piece of lead piping 5 cm long to prevent movement by wind. The sides of the frame (but not the top) were covered by wire netting.

FIGURE 1—ILLUSTRATION OF THE POSITION OF AN EMBEDDED THERMOMETER

Stippling denotes mortar.

On nights during the winters 1972/73 and 1973/74 when it seemed likely that there would be frost on the concrete a pint of tap water—freezing point 0°C—was carried from the office and poured on the concrete at sunset at a distance of

about 2 m from the thermometers. The state of this water was noted each time the thermometers were read. If all the water evaporated during the night, another pint was poured. The experiment could be done only on those nights when operations on the station permitted and the thermometers could not be watched continuously, but observed only at hourly or two-hourly intervals as circumstances allowed. The actual temperature recorded by the surface thermometer was noted, not the minimum.

Results

The water froze on 27 nights and these occasions fall into two categories:

(a) On 3 nights the water had partially frozen at the time of an observation and the temperature of the surface was then presumably very near to freezing point. The reading of the surface thermometer was below 0°C on 2 nights and above 0°C on 1 night; the reading of the embedded thermometer was slightly above 0°C on all 3 nights.

(b) On 24 nights the readings of the thermometers when the water froze are not known. On 15 out of the 24 nights the surface thermometer was already recording temperatures below 0°C while the water was still liquid, and on 13 out of the 24 nights the embedded thermometer was still recording temperatures above 0°C after the water had frozen. These facts accord with those of the first category and suggest that when the water was actually freezing, the reading of the surface thermometer was probably slightly below 0°C and that of the embedded thermometer was probably slightly above 0°C.

For the 24 nights when the water froze between observations, estimates of the readings of the thermometers when freezing occurred were first obtained by assuming that on average the reading of each thermometer was then mid way between the readings before and after freezing. Readings of the two thermometers for all 27 nights when freezing occurred (actual observations on 3 nights and estimates for 24 nights) are summarized in Table I.

TABLE I—READINGS OF SURFACE AND EMBEDDED THERMOMETERS WHEN FREEZING OCCURRED

Thermometer	Highest	Lowest	Mean	Standard deviation
		degrees Celsius		
Surface	+0·5	−2·5	−0·7	+0·8
Embedded	+2·3	−0·5	+0·5	+0·6

As an alternative analysis the readings were plotted on arithmetic probability paper (Brooks and Carruthers, 1953). For this purpose the means of the readings for each thermometer before and after freezing were used to determine the rankings (and hence the probabilities) but both readings were plotted for each probability. The idea was to construct on the paper a straight line for each thermometer which intercepted each range between observations made before and after freezing, and thus to determine a description of the data when the water freezes in terms of a mean, a standard deviation, and a normal distribution. It proved possible to construct such straight lines (which failed to intercept only one or two of the observed ranges) and they are shown in Figure 2. This analysis gave means of −0·7°C and +0·4°C with associated standard deviations of 0·7 deg and 0·4 deg for the surface and embedded thermometers

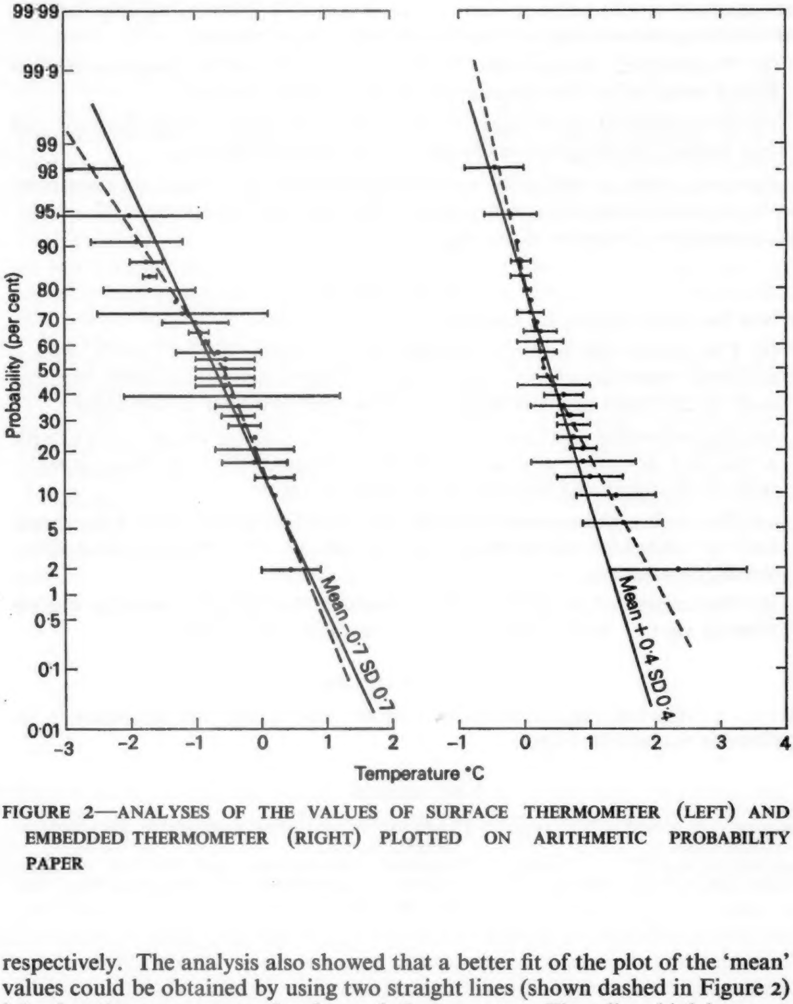


FIGURE 2—ANALYSES OF THE VALUES OF SURFACE THERMOMETER (LEFT) AND EMBEDDED THERMOMETER (RIGHT) PLOTTED ON ARITHMETIC PROBABILITY PAPER

respectively. The analysis also showed that a better fit of the plot of the 'mean' values could be obtained by using two straight lines (shown dashed in Figure 2) joined at the 50 per cent value for each thermometer. These lines kink in opposite directions for the two thermometers, indicating that the distributions of the 'mean' values depart from normal, so that the scatter for the surface thermometer is greater when its indications are more negative than its (negative) average and the scatter for the embedded thermometer is greater when its indications are more positive than its (positive) average.

Further examination of these 'mean' values showed that for each thermometer the departures from 0°C tended to be greater early in the night when the temperature was falling more rapidly than later in the night. Within the limitations of the data the 'mean' values also showed that the surface thermometer indicated 0°C about an hour before the water froze, while the embedded thermometer

indicated 0°C about an hour after the water froze. It is thought likely that the differences in the readings of the thermometers arise because:

(a) The surface thermometer itself radiates and while temperatures are falling cools below the temperature of the concrete surface.

(b) The embedded thermometer is shielded by the surrounding concrete and lags behind the temperature changes of the concrete surface.

For each night on which the water froze the readings of both thermometers before and after freezing were averaged. These averages had a mean of −0·1°C and a standard deviation of 0·4 deg.

Conclusions

When free water freezes on concrete:

(a) The surface thermometer readings are on average about −0·7°C with a standard deviation of 0·7 deg; these readings tend to be more negative early in the night and less negative or even positive later in the night.

(b) The embedded thermometer readings are on average about +0·4°C with a standard deviation of 0·4 deg; these readings tend to be more positive early in the night and less positive later in the night.

(c) The surface thermometer reading falls to 0°C about an hour beforehand and the embedded thermometer reading falls to 0°C about an hour afterwards, on average.

(d) The means of the surface and embedded thermometer readings are on average about −0·1°C with a standard deviation of 0·4 deg.

Acknowledgement

Mr C. L. Hawson suggested this experiment and carried out the analysis on arithmetic probability paper.

References

BROOKS, C. E. P. and CARRUTHERS, N. 1953 Handbook of statistical methods in meteorology. HMSO, p. 101.

RITCHIE, W. G. and VIRGO, S. E. 1973 Embedded thermometers and forecasts of night minimum temperature at Wyton. *Met Mag*, **102**, pp. 179–181.

REVIEWS

Everyday meteorology, by A. Austin Miller and M. Parry. 240 mm × 160 mm, pp. 272, *illus.*, Hutchinson & Co (Publishers) Ltd, 3 Fitzroy Square, London, W1, 1975. Price: £4.95.

The first edition of this book was favourably reviewed in the *Meteorological Magazine* for December 1959. In his preface to this, the second edition, the second author claims that the text has been updated and substantially rewritten; it is a pleasure to be able to agree in this instance with a claim all too frequently made about second editions with small justification.

The book is addressed to the interested layman and virtually no mathematics are used. This does lead to difficulties for example in the description of the Coriolis force. In the text this is related to the spin of the earth, whereas what is wanted for horizontal motion is the concept of the component of spin about the local vertical. It was not made clear to this reader why the Coriolis force should be zero at the equator. This is a tricky point to get over. Possibly the behaviour of a Foucault pendulum could be used; the authors do mention this but do not make the point that the rate of change of direction of swing varies with latitude. In the chapter 'Local influences and local weather' we read that 'in unstable air windward coasts enjoy no evening clearance of shower clouds'. Seaside landladies might prefer to see it pointed out that with unstable air in summer it is often possible to sit on a beach bathed in sunshine and watch the shower cloud building up inland.

But these are minor points. In the main the lay reader is given a clear impression of how synoptic meteorology works, from the making and collection of observations to the drawing and use of synoptic charts for forecasting. He is also shown how an appreciation of local influences may enable him to interpret a general forecast so that it is more directly useful to himself. A new chapter discusses briefly the highly topical subject of pollution in the atmosphere. The authors do not attempt too much over-simplification in that, for example, they describe a frontal model but point out that on a particular occasion an actual front may depart significantly from this model. It is thus possible for the general reader to understand why the professional forecaster does not achieve or expect to achieve complete accuracy on every occasion.

H. HEASTIE

Instant wind forecasting, by A. Watts. 225 mm × 165 mm, pp. 119, *illus.*, Peter Davies Ltd, 15–16 Queen Street, Mayfair, London W1X 8BE, 1975. Price: £2·90.

The title may evoke a reaction of horror or at least disbelief on the part of the professional meteorologist, but one has to recognize that there is today an increasing number of people whose recreation depends on or involves using the wind and who need some elementary guidance on its behaviour and predictability. The aim of this book is to provide this guidance and 'to help sort out the probable trends in the wind from a mass of possibilities' (page 6). It is written for the sailor, in particular the dinghy sailor.

The author, a one-time professional meteorologist, has no illusions as to the problems and difficulties in forecasting the wind, and he rightly restricts his discussion to short-term trends. Using photographs and word pictures representing a wide variety of weather situations he seeks to tabulate the likely changes. This is a task in which complete success is probably impossible, and even to attempt it is praiseworthy. Many of the tables provide good and comprehensive summaries of all the possibilities under a particular heading; for instance the table on pages 36 and 37 under the caption 'Will there be a big blow?'. Given a spare hour or two it is an interesting exercise to sample what may be

gleaned from them (hardly instant!). One enters the maze first of all by identifying the sort of day it is under 'the wind's day', then, turning to the page appropriate to that sort of day, the student is led into a series of tables showing the possible diurnal, local and micro changes to look for, and then on to the sections which deal with these changes in more detail.

The main drawback with the book is that in common with others of his recent publications the author seems to want to develop a mystique rather than an elementary understanding of the patterns of weather which he identifies. His essentially empirical approach to the subject might be justified for the particular audience which he has in mind were it not for his frequent use of semi-professional jargon which must be lost on the majority of readers: 'nocturnal polar airstreams', 'early katabatics', 'sea breeze frontal systems', to name but a few examples. What does he mean when he says 'cyclonic isobars inhibit sea breezes'? The sea-breeze is discussed at length but the various evidences of the breeze are not linked to any simple model which might help the reader to understand what they all mean; yet he is expected to be able to differentiate (page 9) between 'coastal slope winds', 'katabatic winds', and 'mountain and valley winds', as being sufficiently dissimilar one from another to require separate treatment.

The book is attractively produced and there are some good photographs, but most of the diagrams are poorly conceived and lack adequate captions. With this latest volume the author should be able to cash in on his earlier successes with *Wind and sailing boats* and *Instant weather forecasting*, and it is probably the best companion on the market at the moment.

D. M. HOUGHTON

551.509.317:551.509.33:551.583.2

LETTERS TO THE EDITOR

The construction of 500-millibar charts for the eastern North Atlantic–European sector from 1781

Although Mr Kington (*Met Mag*, **104**, pp. 336–340) does not say exactly how he arrived at the thickness lines on his Plate II (he quotes nine separate factors as influencing his decisions) the resulting values over Scandinavia (for instance) are so improbable as to be virtually certain to be wrong by a large amount.

The extreme minimum of thickness in December over Stockholm in the period 1951–66 as quoted in *Geophysical Memoirs* No. 117 is about 504 decametres (dam) whereas Kington's value is near 480 dam with even lower values farther north. The surface temperature at Stockholm on 28 December 1783 was $-15°$C. I have examined the 1000–500-mb thickness values over Stockholm on the days when the temperature at midday at Stockholm in the 1960s was between $-10°$ and $-20°$C. The mean thickness associated with these surface

temperatures was 510 dam with a standard deviation of 5 dam, so that Kington's 480 dam is about six standard deviations away from the mean thickness associated with the recorded surface temperature. Such a thickness value would be rare in December even over Siberia or northern Canada.

A temperature of −15°C at Stockholm in December is not so rare a phenomenon as to suggest that associated 1000–500-mb thicknesses would be similar to present-day extreme December values over Siberia.

I conclude that 510 dam is the most likely thickness value over Stockholm on 28 December 1783.

At the same time as these unprecedentedly low thicknesses were drawn over Scandinavia, values over Italy (for example) are within 6 dam of the maximum recorded in the period 1951–66. Mr Kingston's gradients over Europe are certainly much too strong.

An obvious check of the methods used could be made by preparing some 500-mb charts in the recent past and comparing with the real thing.

A more satisfactory method of producing thickness charts (and hence 500-mb charts) for years without upper-air data would be to carry out systematic regression analysis over a network of points, relating surface temperature to 1000–500-mb thickness in years for which data are available and then applying the regression equations to the earlier years. Perhaps this is what Kington intends in his method (a) (2) but Figure 1 does not suggest that he has carried this out rigorously.

Assistant Director (*Synoptic Climatology*), R. A. S. RATCLIFFE
Meteorological Office,
Bracknell.

Reply by Mr J. A. Kington:

In his letter, Mr Ratcliffe makes some criticisms of the contents of my paper on a method of constructing charts. In the following discussion these criticisms are answered with some of the points being clarified and expanded. A second illustrative example is given of a post-1950 case for comparison.

(a) The method of arriving at the thickness lines given in Figure 1 of my paper has been questioned. I agree that it was not made clear whether all or only some of the techniques listed under the heading Construction of 1000–500-mb chart were used in the drawing up of this chart. Firstly it should be realized that to construct a series of deduced 500-mb charts based on all the techniques given would require a fully operational program of work running in conjunction with my present project of preparing and analysing surface daily weather maps from 1781 and this at present is not in action. Indeed, the main object of my paper was to indicate the method with which it would be possible to construct a series of 500-mb charts from 1781. At the same time, however, I thought it would be a useful and interesting exercise to include an illustrative example, employing as many of the construction factors as are readily available to me at present, that is to say use of synoptic-climatological links between 1000–500-mb thickness and surface synoptic features such as standard pressure patterns, alignment and types of fronts and change-over zones in precipitation forms,

together with a consideration of the relationship between total thickness and wet-bulb potential temperature. Perhaps I should have made this point more clearly when presenting the chart.

(b) With regard to the statement 'the resulting values over Scandinavia (for instance) are so improbable as to be virtually certain to be wrong by a large amount', I would add that the extreme minimum of thickness in December over Stockholm in the period 1951–66 is given as 498 dam in Figure 4(l) on page 28 in *Geophysical Memoirs* No. 117 (Moffit & Ratcliffe, 1972) and not 504 dam as quoted by Mr Ratcliffe. However, although I agree that my value of 480 dam would be extremely subnormal, in view of the comments given below on the prevailing synoptic situation I cannot accept that it is wrong by a large amount.

In my original paper I only gave reference to the synoptic situation for 27 and 28 December 1783; however, from an examination of the daily weather maps for late December 1783 it is interesting to note that the general weather pattern which gave rise to the situation on 27th/28th began on 21st/22nd, when an anticyclone over central Europe moved north-eastward to become a blocking high over Scandinavia. Subsequently, high pressure also developed over the Norwegian Sea and Icelandic region on the 27th and 28th with cold-air advection westwards and south-westwards over the Low Countries, northern France and the British Isles. Minimum air temperatures in these areas fell to between −11 and −16°C and rivers and lakes became frozen over. The severe temperature regime of this airstream provides an indication of the very cold air that had been involved in the anticyclonic circulation over Scandinavia and also the probability that related 1000–500-mb thickness values would have been much below normal.

In a synoptic study of winter anticyclones over Scandinavia, Miles (1961) has stated that 1000–500-mb thickness anomalies associated with these systems were in general some 15 to 20 dam below normal during the first two days over the region. Thus assuming a mean value over Scandinavia of 528 dam in December (Moffitt & Ratcliffe, 1972), the minimum thickness over the region could have been about 510 dam by the 24th. This is in agreement with the value given by Mr Ratcliffe for the mean thickness associated with surface temperatures of −10 to −20°C over Stockholm. However, these estimates are based on generalized or mean values and in a particular situation displaying extreme characteristics, as that described above for 28 December 1783, I suggest that even lower thicknesses should be considered. Also, the possible effect of further cooling in a blocking situation over Scandinavia after the initial period should not be overlooked. For example, if overall cooling continued in the system at an equivalent rate of about 3 dam per day from 24 to 28 December, a value of 498 dam, that is to say, equivalent to the extreme daily minimum of the period 1951–66, or within −3 to −2 of Ratcliffe's mean value of 510 dam could have been obtained by 28 December 1783. The possibility that extreme values outside the limits of the 1951–66 analysis may have occurred in the past and for that matter could well occur in the future should not be ruled out. The main point of difference here seems to be whether we are dealing with a mean or extreme minimum, and I would suggest that the most likely thickness value over Stockholm on 28 December 1783 should be at least 12 dam lower than the estimate given by Mr Ratcliffe. However, the question would be more satisfactorily

resolved when and if a project utilizing all the techniques listed is put into operation.

(c) With reference to the statement that 'an obvious check of the methods used could be made by preparing some 500-mb charts in the recent past and comparing with the real thing', a post-1950 example has now been constructed using the same techniques that were available to me for drawing up the original illustrative example. The modern situation selected is that for 30 December 1962. Only surface data (extracted from the *Daily Weather Report*) which would have been available for preparing a daily weather map for the 1780s have been used. It will be seen from Figure 1 that despite 500-mb contour heights being generally

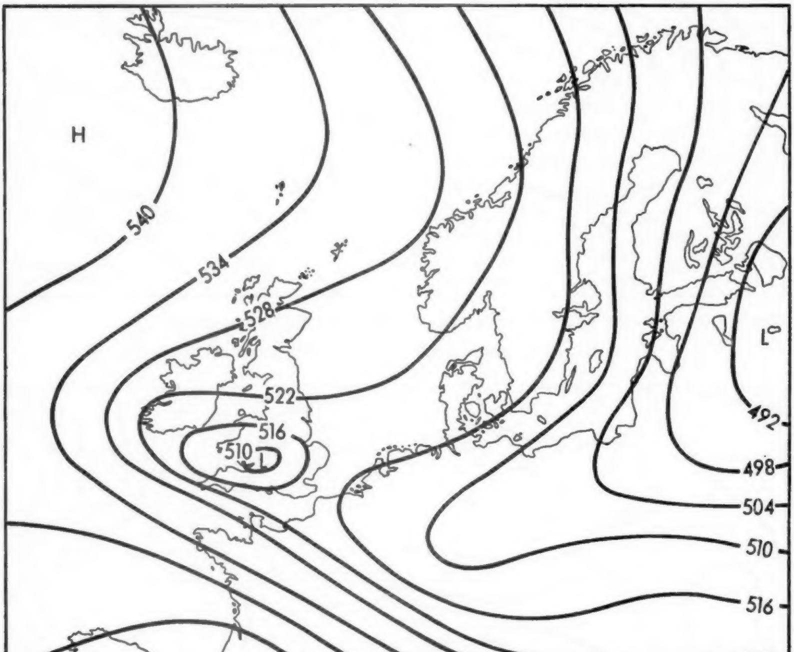


FIGURE 1—500-mb CONTOURS AT 1200 h ON 30 DECEMBER 1962 CONSTRUCTED WITH AVAILABLE TECHNIQUES BY J. A. KINGTON FROM THE METHOD DESCRIBED

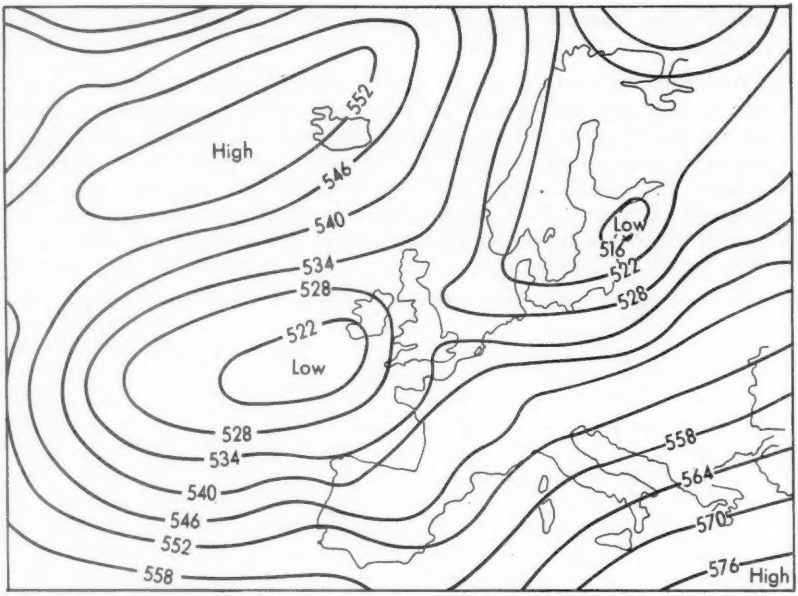


FIGURE 2—500-mb CONTOURS AT 0000 h ON 30 DECEMBER 1962
From the *Daily Aerological Record* of the Meteorological Office.

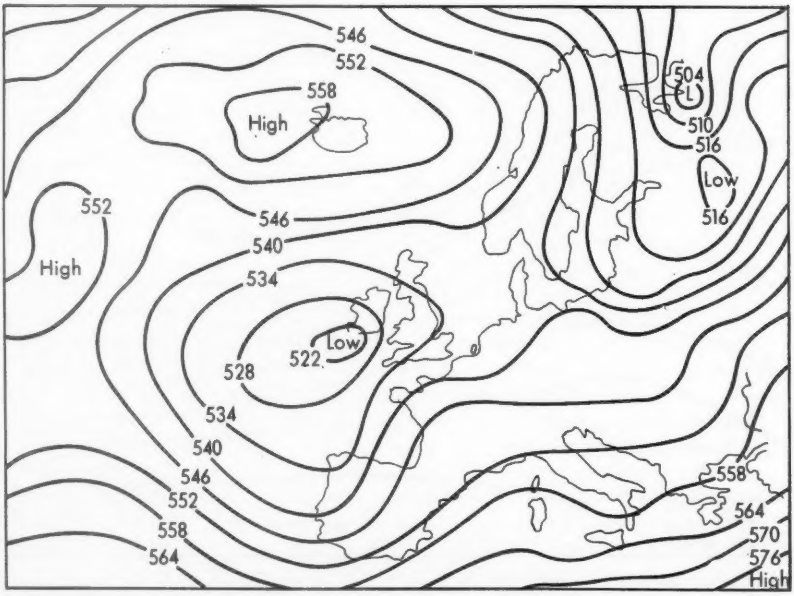


FIGURE 3—500-mb CONTOURS AT 0000 h ON 31 DECEMBER 1962
From the *Daily Aerological Record* of the Meteorological Office.

lower, the main features of the constructed pattern are similar to those of the actual patterns (see Figures 2 and 3). This reinforces my argument that even with a limited use of the techniques suggested a reasonable approximation of the general pattern can be obtained. How much more satisfactory it would be using all the techniques suggested!

(d) In his final paragraph Mr Ratcliffe states 'A more satisfactory method of producing thickness charts (and hence 500-mb charts) for years without upper-air data would be to carry out systematic regression analysis over a network of points, relating surface temperature to 1000–500-mb thickness in years for which data are available and then applying the regression equations to the earlier years.' This is indeed what was intended in section (a) (2) of my paper and I agree that it would be invaluable if 1000–500-mb thickness values at selected points, corresponding to present upper-air stations, could be related to air temperatures. In utilizing a method based on work by Boyden (1962), Parrey (1972) has devised a means of forecasting maximum temperatures from 1000–500-mb thickness values; from an analysis of surface and upper-air data for the five-year period 1964–68, a series of diagrams has been prepared in which the 1000–500-mb thickness at midday is related to maximum temperature, time of year, and winds from each of the four quadrants: north-east, south-east, south-west and north-west. From these diagrams, a sample of which is given in Figure 4, it is possible to read off maximum temperatures for as many days ahead as forecasts of 1000–500-mb thickness and surface pressure patterns are available. This is

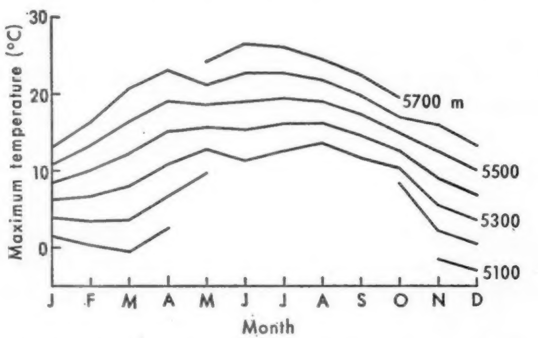


FIGURE 4—MAXIMUM TEMPERATURE RELATED TO 1000–500-mb THICKNESS FOR GEOSTROPHIC WINDS IN THE NORTH-WEST QUADRANT FOR EACH MONTH OF THE YEAR (From Parrey, 1962)

almost precisely the technique I had in mind for determining spot values of the 1000–500-mb thickness at a network of points corresponding to present upper-air stations since it would be equally possible to obtain from similar series of diagrams estimates of 1000–500-mb thickness values for as many days as surface historical weather maps at 14 h are available from 1781.

In conclusion, I should like to say that Mr Ratcliffe's criticisms have afforded me the opportunity to clarify certain points concerning the illustrative example and to enlarge upon the subject in general, for which I am grateful. However,

the main object in presenting my paper remains the same, that is to indicate that the material is available and techniques are possible for constructing a series of historical 500-mb charts from 1781 in order to lengthen the period over which a reasonable three-dimensional representation of the atmosphere can be obtained for use with synoptic-climatological and climatic-change studies.

Climatic Research Unit,
School of Environmental Sciences,
University of East Anglia,
Norwich, NR4 7TJ.

J. A. KINGTON

REFERENCES

BOYDEN, C. J.	1962	Forecasting of maximum surface temperature from 1000–500-millibar thickness lines. *Met Mag*, **91**, pp. 242–246.
MILES, M. K.	1961	Factors associated with the formation and persistence of anticyclones over Scandinavia in the winter half of the year. *Scient Pap, Met Off*, No. 8.
MOFFITT, B. J. and RATCLIFFE, R. A. S.	1972	Northern hemisphere monthly mean 500-millibar and 1000–500-millibar thickness charts and some derived statistics (1951–66). *Geophys Mem*, **16**, No. 117.
PARREY, G. E.	1972	Forecasting temperatures for the gas and electricity industries. *Met Mag*, **101**, pp. 264–270.

CORRECTION

Meteorological Magazine, November 1975, p. 333, Figure 1: The ordinate axes should be labelled 'mW cm^{-2}' and the numerical values implied by the curves should be divided by 60.

OBITUARIES

It is with regret that we have to record the death of Mr K. Richardson, Senior Scientific Officer, Plymouth, on 17 October 1975, and of Mr D. F. Baker, Higher Scientific Officer, Boscombe Down, on 9 November 1975.

THE METEOROLOGICAL MAGAZINE

VOL. 105 NO. 1243 FEBRUARY 1976

CONTENTS

NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire, RG12 2SZ, and marked 'For Meteorological Magazine'.

The responsibility for facts and opinions expressed in the signed articles and letters published in this magazine rests with their respective authors.

Complete volumes of 'Meteorological Magazine' beginning with Volume 54 are now available in microfilm form from University Microfilms Ltd, St Johns Road, Tylers Green, High Wycombe, Buckinghamshire, England.

Full size reprints of out-of-print issues are obtainable from Johnson Reprint Co. Ltd, 24–28 Oval Road, NW1 7DX, London, England.

Issues in Microfiche starting with Volume 58 may be obtained from Johnson Associates Inc., P.O. Box 1017, Greenwich, Conn. 06830, U.S.A.

Printed in England by Heffers Printers Ltd, Cambridge
and published by
HER MAJESTY'S STATIONERY OFFICE

60p monthly **Annual subscription £8.28 including postage**

Dd. 289060 K16 2/76 ISBN 0 11 724368 X